LBL-21030
UC-28

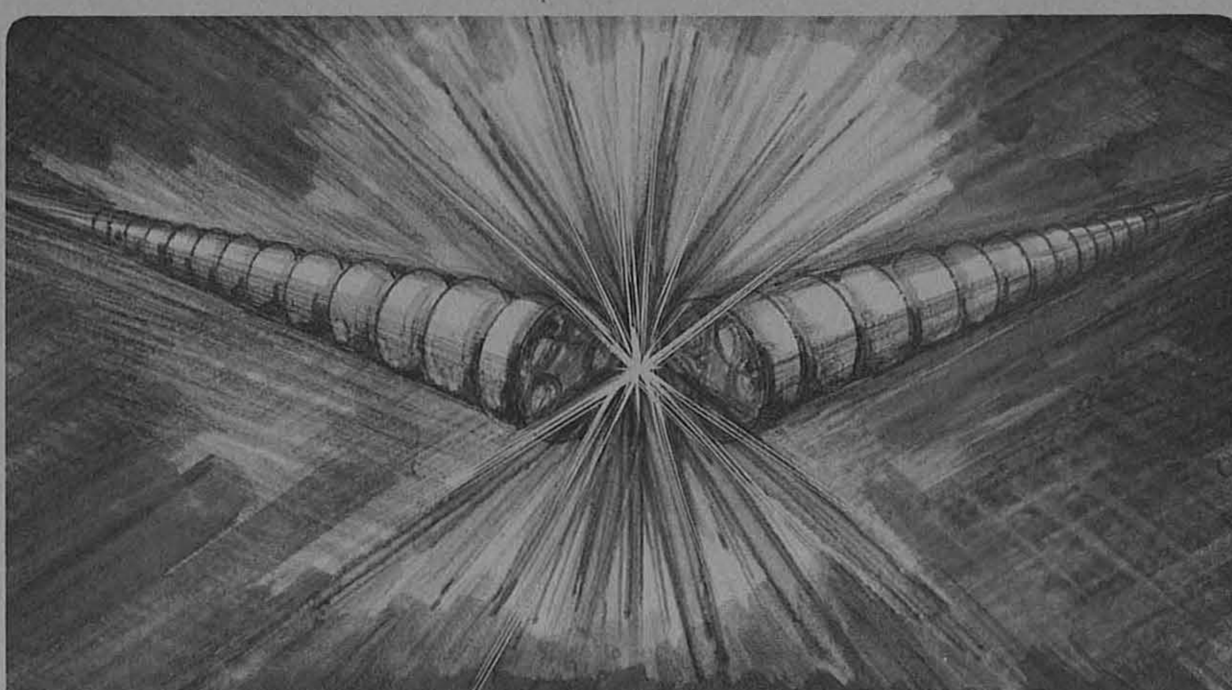
Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

DESIGN OF 15 mm COLLARS FOR SSC DIPOLE MAGNETS

C. Peters

March 1986



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price Code: A02

LBL-21030
SSC-MAG-66

DESIGN OF 15 mm COLLARS FOR SSC DIPOLE MAGNETS*

Craig Peters

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

March 1986

*This was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

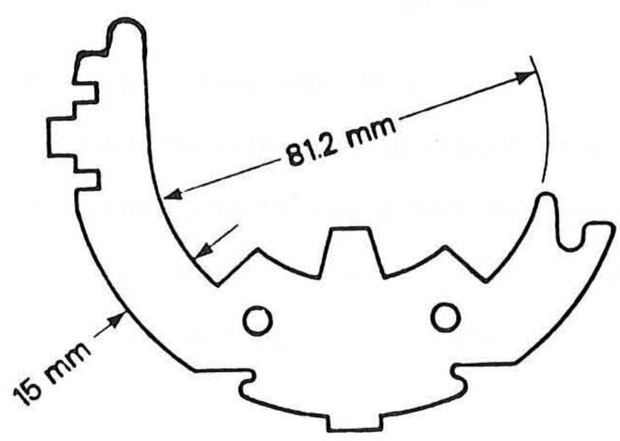
DESIGN OF 15 mm COLLARS FOR SSC DIPOLE MAGNETS

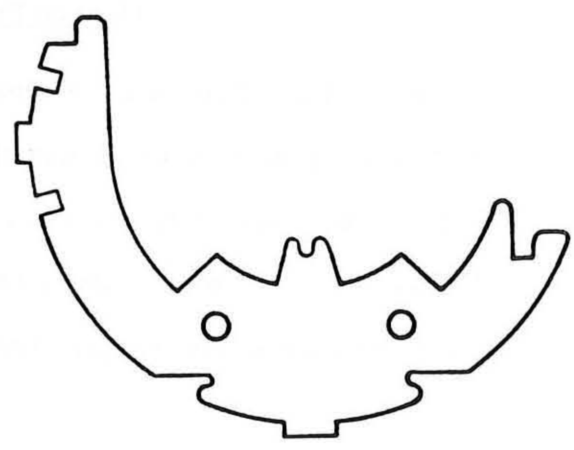
Craig Peters

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Introduction

Beginning in 1985, ten 1-m long dipole magnets of the SSC design "D" cross section have been constructed and tested at LBL. In each model a collar type structure was used to contain and support the coil assembly at assembly and during operation at 4K. The collar structure must provide enough coil compression to minimize training as well as guarantee the coil cross section dimensions. Three types of collar designs were used. This paper will examine the behavior, measured and predicted, of two types of 15 mm stainless steel collars used on eight of the ten models. The two geometries used are shown in Figs. 1 and 2. The only significant difference is the keyway location and





XBL 863-940

Fig. 1. Type A Collar (used on Model C2).

Fig. 2. Type B Collar (used on Model C4) through MD2).

the interlocking joint design. Figure 1 shows Type A used in the first of the eight models. These collars were fabricated by laser cutting. Figure 2 shows Type B used in the remaining seven models. These were punched out using a punch and die.

The remainder of the paper is organized as follows:

1. Mechanical measurement of 15 mm S.S. collars used on eight 1-m dipole models.

2. Discussion of observed behavior and preliminary design criteria.

3. Finite element analysis modeling of collars.

4. Correlation of FEA models and measured behavior.

5. Predicted behavior on alternate collar designs.

6. Conclusions.

Mechanical Measurements of 15 mm Stainless Steel Collars Used on Eight 1-m Dipole Models

Three types of mechanical measurements are routinely made pertaining to the collars; vertical and horizontal diameters of the collars before and after collaring, coil pressure in each layer during model construction and testing, and measurements of the used collars after model disassembly. Coil pressure measurements are not collar measurements per se, but coil pressures are a direct reflection of collar behavior.

Pressure Gages

Four pressure gages were installed in one of the six inch collar packs in each model, two gages in each layer. References 1 and 2 describes the gages and calibration procedure used. The gages are designed to read azimuthal coil pressures only. The outer layer gages must be checked to insure they do not respond to radial pressure from the inner layer. It is important that the gages be fully temperature compensated, that they be calibrated after being installed in their respective collars, that the collars are supported during calibration by their keyways (as they will be when used), and that the calibration offset at 80K be measured. Tests have been made to insure that this measured offset is load independent. To date, we have not measured thermal offsets at 4K, but assume there is little change from that measured at 80K. Also, it is important that the entire measurement set up from the cryostat to readout be wrung-out using dummy gages with no load in the cryostat during cooldown to see if any unexpected thermal offsets show up.

Measurements

Table I shows the diameter deflections for each model. The measured deflection is the measured zero load diameter, with all the pin and key slop taken out, subtracted from the collar diameter measured after collaring.

Table II shows the coil stress data for each model in the collaring press, after collaring, prior to cooldown, and at 4K.

Inspection of collars removed from magnet assemblies show yielding has occurred in the tab area above the upper keyway of collar Type B as viewed in Fig. 2. Direct measurement and optical measurements on the CMM at Fermi National Laboratory show this keyway has opened up at its center point by 0.010 to 0.015 inches. This problem is also reflected in the large vertical diameter deflections for models C4 through C8 in Table I. Type A collars with a thicker tab area above the upper keyway show no yielding.

TABLE I

Average Diameter Deflections of 15 mm Collars Measured After Collaring

Model #	Vertical Diameter Deflection (mils)	Horizontal Diameter Deflection (mils)
C2 (Type A Collars)	9.0	1.0
C4 (Type B Collars)	15.0	4.0
C5	12.0	5.0
C6	15.0	3.0
C7*	17.0	8.0
C8*	23.0	7.0
MD1	10.0	6.0
MD2	9.0	8.0

*used collars

TABLE II

Coil Azimuthal Pressure During Construction and Cooldown

(For each model first data line is for inner layer,
second data line is for outer layer.)

Model #	In Press (Kpsi)	After Collaring (Kpsi)	(% Loss)	Prior to Cooldown (Kpsi)	(Creep Days)	4K (Kpsi)
C2 inner	18.5	9.6	(48)	7.1	(12)	2.0
outer	17.2	8.1	(53)	7.5	-	6.0
C4	19.4	11.1	(43)	9.5	(19)	4.3
	16.2	6.1	(62)	5.8	-	3.8
C5*	21.5	6.7	(69)	5.4	(6)	1.5
	13.8	5.6	(59)	3.8	-	2.9
C6	23.4	11.8	(50)	-	-	2.4
	14.7	5.22	(64)	-	-	3.3
C7*	18.5	-	-	3.2	-	1.5
**	22.8	-	-	6.7	-	6.1
C8*	24.0	10.5	(56)	-	-	2.5
**	25.0	10.3	(59)	-	-	2.3
MD1	13.6	-	-	-	-	-
	23.8	-	-	-	-	-
MD2	20.2	9.8	(51)	-	-	-
	13.1	6.5	(50)	-	-	-

*This models were heat crept after collaring

**This model has used collars.

Observed Behavior and Preliminary Design Criteria

Coil Stress History

During construction, the coils are initially compressed very tightly to install or "key" the collars around the coil assembly. As the collared coil assembly is removed from the collaring press, the coil load is transferred to the collars. As the collars elastically deform outward, or springback, the coil pressure drops and the coil/collar system comes to equilibrium. The assembly is eventually cooled down to 4K, further reducing coil compression though differential contraction of the coil and collars. Figure 3 illustrates the qualitative coil stress levels through the construction and cooldown phases.

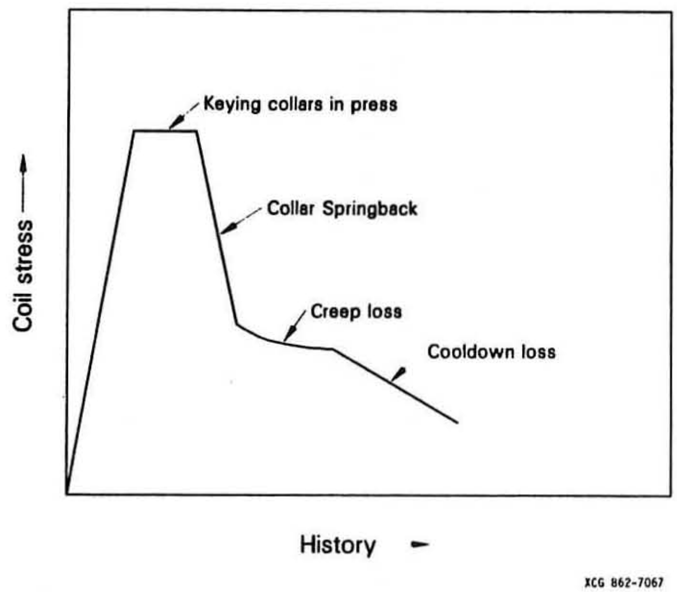


Fig. 3. Typical Coil Stress History

Based on the measured coil stress data (Table II), the following general conclusions pertaining to coil stresses with keyed 15 mm S.S. collars can be seen:

1. Coil pressure decrease due to collar springback is 50% to 60%.

2. Coil stress relaxation (creep) takes place quickly after collaring and averages 15%. This is in agreement with data presented in Reference 3.

3. Pressure loss during cooldown to 4K averages about 3,000 psi. The inner layer looses more than the outer layer.

Preliminary Design Criteria

It will be helpful at this point to consider some quantitative coil stress limits to apply to the coil stress history diagram. The following levels are tentative and, no doubt, will be modified as more testing is done.

1. Maximum coil stress during collaring should be limited to 15,000 psi. Cable insulation breakdowns have occurred at stresses approaching 20,000 psi.

2. Residual coil stress after cooldown should be greater than 3,000 psi. This is supported by training data and analysis of coil forces and motion during operation (Ref. 1).

3. The collar must not have any significant yielding. Yielding results in lower coil stresses as well as introducing coil cross dimensional section variations.

We can now update our coil stress history diagram and make these levels the minimum criteria which a given collar design much produce (Fig. 4).

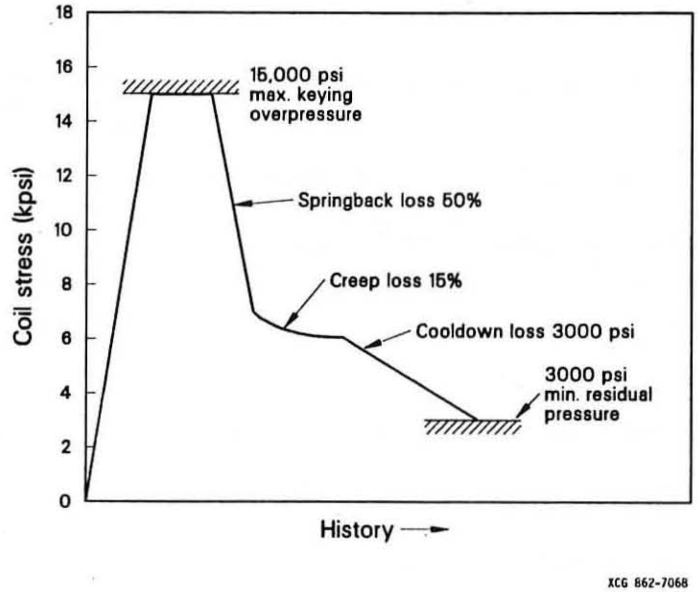
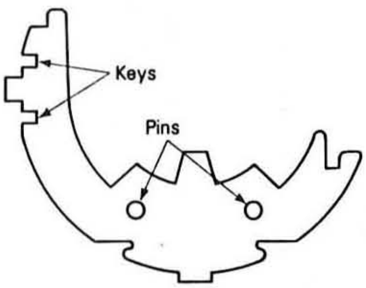
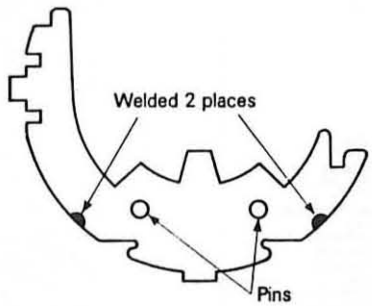


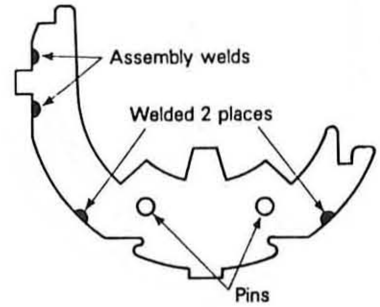
Fig. 4. Coil Stress History with Stress Limits

Finite Element Analysis of Collar Designs

In order to better understand observed collar behavior and to evaluate new designs, FEA modeling using the ANSYS program was undertaken. Five 15 mm S.S. collar configurations were looked at; Type A and B which we have experience with, a modified keyed type, and two types of welded designs. The three new types are shown in Figs. 5, 6, and 7. For each type a complete model of about 1500 elements was constructed, including pins and keys. An average azimuthal coil load of 7,000 psi was applied. This corresponds to the needed coil stress after collaring in order to arrive at the 3,000 psi stress after cooldown as suggested above. Boundary condition of symmetrical motion of pin and key pairs was imposed. The distribution of imposed forces on the collar model must be consistent with the relative motion between adjacent collars and the resulting redistribution of load. In other words, a load condition may not make sense after adjacent collars have moved relative to each other. This can also be taken care of by modeling the coils within the collar, which was not done for these models.







XBL 863-941

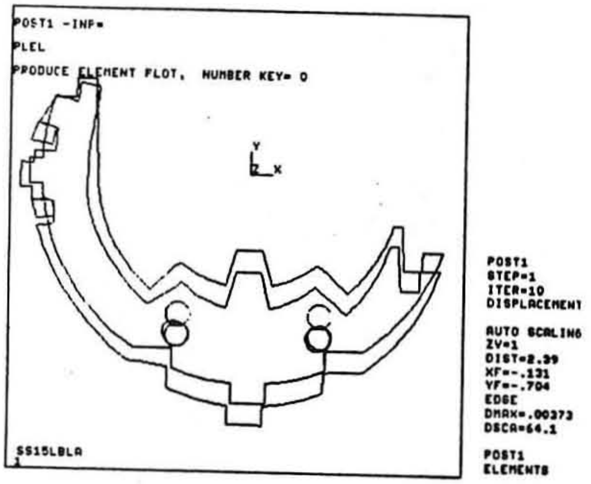
Fig. 5. Modified Keyed

Fig. 6. Partially Welded (welds supplement pins only)

Fig. 7. Fully Welded (No Keys)

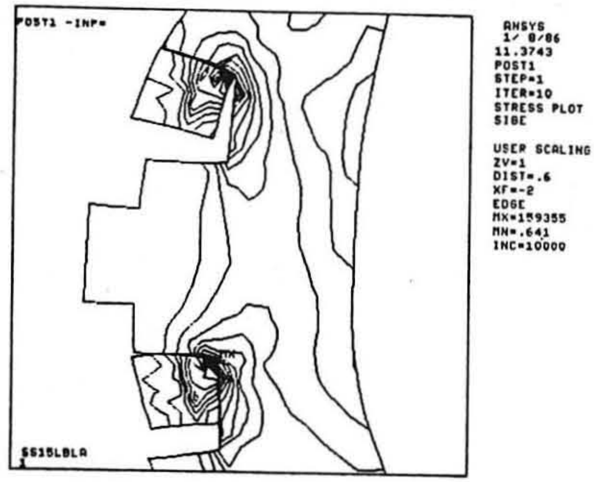
Stresses and deflections for each collar type were examined. Typical results are shown in Figs. 8 and 9 for the modified keyed type of collar. The peak stress and deflection results for all five collar types are shown in Fig. 10. The deflection plotted is the average radial deflection doubled to give the average diameter deflection for the total collared coil cross section. An interesting point to note is that each of the different keyed type collars have nearly identical deflections whereas the peak stress is very sensitive to key design. In all the keyed collar cases the peak collar stress was located at the root of the upper keyway.

The average diameter deflection parameter plotted against the collar load will produce a collar stiffness line. Collar stiffnesses are plotted in Fig. 11. All keyed type collars have the same stiffness.



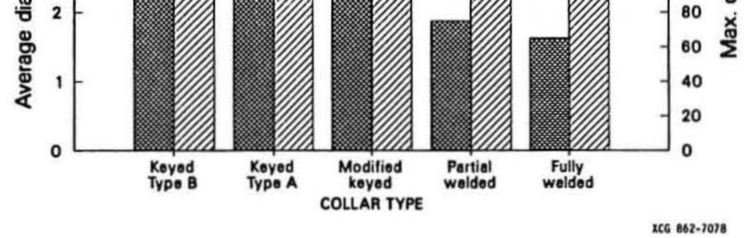
XBL 863-942

Fig. 8. Typical Deflected and Undeflected Collar Produced by ANSYS.



XBL 863-943

Fig. 9. Typical Collar Stress Stress Pattern Produced by ANSYS.



XCG 862-7078

Fig. 10. Stress and Deflection for Five 15 mm S.S. Collar Types

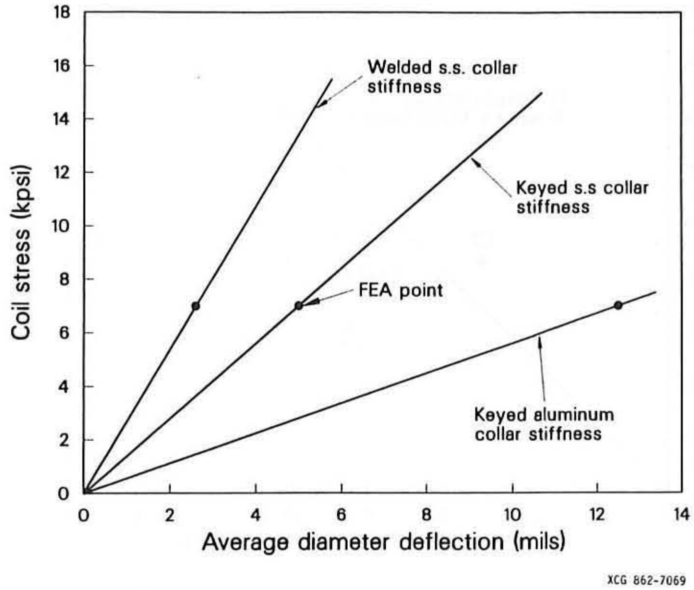


Fig. 11. Collar Stiffness 15 mm S.S. Collar Types

Correlation of FEA to Measurements on Existing Collar Types

The Analysis predicts that Type B keyed collars have a 45% higher peak stress at the upper keyway than Type A collars. As mentioned at the end of the Mechanical Measurements Section, yielding at this location was found to often have occurred on Type B collars while not on the Type A collars.

When the residual coil stress (Table II, column 3) is plotted on the collar stiffness plot against the collar diameter deflection (Table I) for the various models tested, an interesting pattern appears. Figure 12 shows the C2 collar data point (Type A) near the predicted stiffness line and the C4 through MD2 points (Type B) somewhat below the line, indicating a lower than expected stiffness for the Type B collars.

What, in fact, occurred in these collars is that as the coil load is transferred to the collars, the collars deflect as predicted until significant yielding onsets. At this point the collar stiffness line slope becomes much flatter thus arriving at the measure data points for the Type B collars. All this is to say that the type B collars have a

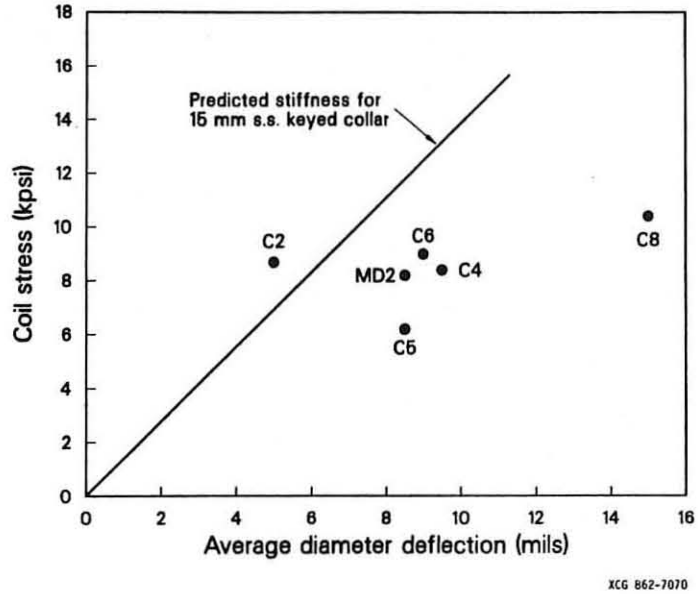


Fig. 12. Predicted and Measure Stiffness for 15 mm S.S. Collars

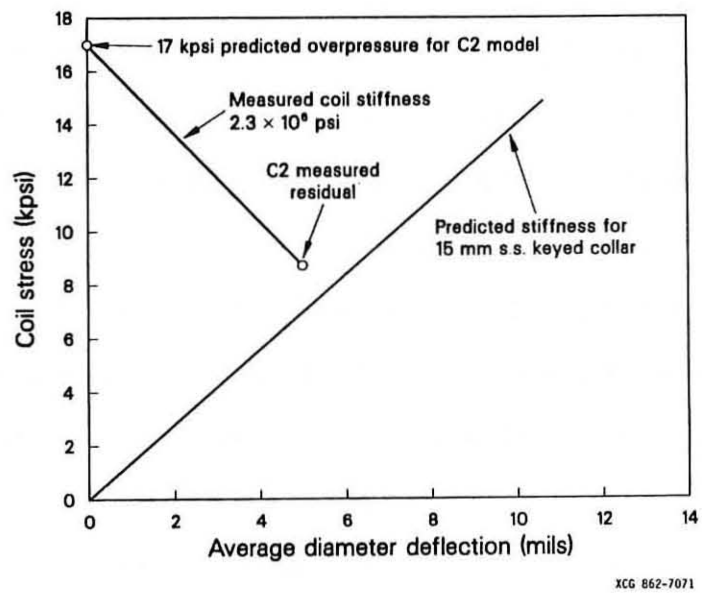


Fig. 13. Model Prediction of C2 Overpressure

strength problem whereas Type A collars have some strength margin (although small as will be seen).

The understanding and prediction of collar behavior can be further pursued by the following exercise. Starting at the C2 residual pressure point on our stiffness diagram Fig. 12, we can work backwards toward zero deflection to predict what the coil pressure was during the keying step. At that point the collars are forced into their non-deformed shape by the collaring press. Adding this coil stiffness line, Fig. 13, (using a measured average coil modulus of 2.3×10^6 psi over the collaring pressure range) we see our model predicts 17,000 psi coil pressure during keying. This predicted value correlates well to the actual measurement of 18,000 psi (see Table II). We may now, with some confidence predict the in-press coil stress and residual stress after collar springback for new collar configurations.

Predicted Behavior on Alternate Collar Designs

Now we are at a point where we can begin to examine alternate collar designs and their ability to meet the suggested design criteria. Three designs are considered: The S.S. modified keyed type, the 15 mm S.S. fully welded type, and aluminum collars of the modified keyed type. Analysis of aluminum was done and as expected predicts the same stresses and about 3 times the deflections for the same load as the S.S. collars.

The collar strength problem in the keyed S.S. collars can be readily eliminated by moving the keyways to the locations for the modified type shown in Fig. 5.

The general approach to comparing designs will be to extract overpressure levels (peak coil stress in keying operation) and residual pressure levels (after springback) from the coil/collar stiffness plots for the different alternative collar designs.

For each type considered, we may ask two questions: "What residual pressure will be left when the overpressure was 15,000 psi during keying?" and, secondly, "For a given residual after collaring pressure requirement, what is the overpressure at keying?". We can now proceed to the coil/collar stiffness plots and plot two coil stress lines. This is